RELATIONSHIP BETWEEN FREQUENCY OF RFID TAGS AND ITS ABILITY TO PENETRATE FRESH CONCRETE

A Thesis

by

RAJASEKARAN SRIDHARAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2010

Major Subject: Construction Management

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Approved by:

Chair of Committee,	Julian Kang
Committee Members,	Ivan Mutis
	Gwan Choi
Head of Department,	Joe Horlen

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ABSTRACT

Relationship between Frequency of RFID Tags and Its Ability to Penetrate Fresh Concrete. (May 2010)

Rajasekaran Sridharan, B.Tech, NIT, Trichy

Chair of Advisory Committee: Dr. Julian Kang

The concrete maturity method can be utilized to determine in situ strength of concrete. It uses the temperature of concrete to determine a maturity index that can then be used to determine strength of concrete. However, monitoring the concrete temperature using thermocouples brings up a wiring issue, which is not advisable in an equipment and human intensive area like a construction site. One of the ways to get around this wiring issue is to use Radio Frequency Identification (RFID) technology, which is capable of transmitting information wirelessly. Previous research implemented using ultra high frequency RFID tags embedded in fresh concrete found that water could be the impediment for transmitting RFID signal from within concrete during early stages of curing. From literature it was found that lower the frequency, better the chances of the wave penetrating water. The objective of the research was to figure out whether the frequency of RFID tags has any relationship with the readability of RFID tags embedded in fresh concrete.

For this investigation, low frequency, high frequency, and ultra high frequency RFID tags were tested within fresh concrete to see any difference between tags in terms of transmitting information. This experiment was carried out in a controlled space to reduce the number of variables affecting the experiment outcome. The low frequency, high frequency, and ultra high frequency RFID tags were placed within 2 in x 3 in x 2 in wooden formwork at a depth of 4 in, 8 in, and 12 in. Ready mix concrete was poured into the formwork and 3 concrete cubes were cast with the tags embedded within them. Readers that could be connected to a laptop were used to monitor and collect the time at which these RFID tags can be detected.

The test showed that the RFID signals from the low frequency tags at all depths were detected as soon as concrete was poured. The Ultra High Frequency tags placed at the 4" level could be detected 15 minutes after concrete was poured. The UHF tags at the 8" level could be detected after 30 minutes. The UHF tags at the 12" level took on an average 2 hours to be detected from the vicinity of the formwork. The greater the depth at which the ultra high frequency tag was buried the longer it took for it to be detected. The high frequency tags could be detected only at the 4" level. The reason the performance of the HF card degraded in concrete could be because it uses an aluminum foil antenna which is more susceptible to the environment changing the relative permeability. A copper wire antenna could have fared better in this condition, increasing the chances of detecting the tag. Moreover a passive tag was used. The read range and chances of detection could have been increased had an active tag been used. The power of the reader that was used was also very less which might have contributed to the tag not being detected.

Among the tags that were used in the experiment it was found that low frequency tags was the tag that could be detected the earliest after concrete was poured into the forms. However, the maximum read range of the tag observed in the experiment was 20" which is too small a distance to be used on an actual construction site.

DEDICATION

To my family

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Julian Kang and my committee members, Dr. Ivan Mutis and Dr.Gwan Choi, for their guidance and support throughout the course of this research.

I would first like to thank Eddie LaCost of Texas Instruments for providing us the equipment for the research. I am greatly indebted to James Titus for his advice and patience in helping me with the form work. Thank you, Parsa and John for helping me throughout the experiment. I am greatly indebted to my roommate Siddhartha for helping me out countless number of times. I would also like to thank Dawn who unflinchingly bore all my nagging and stupid questions.

Finally, thanks to my family for their encouragement and selfless love, which made it possible for me to be where I am today.

NOMENCLATURE

LF	low frequency
HF	high frequency
UHF	ultra high frequency
RFID	Radio Frequency Identification

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1. INTRODUCTION

Delivering a project on time is very important for any contractor. `In many cases the contractor finds himself spending more time on a task than needed. If that task happens to be a critical task this increases the project duration. This invariably means that the contractor has to find ways to reduce the duration of other succeeding activities. One of the most critical activities is the curing of concrete. Formwork needed to support fresh concrete cannot be removed until concrete has been cured. The presence of formwork impedes the carrying out of succeeding activities in that area. So something has to be done to get the project moving. An easy way to get this done is to remove the formwork earlier than is advisable. Sometimes formwork is removed before the concrete can set and achieve strength.

The American Concrete Institute has found that reinforced concrete structures fail most often due to the failure of formwork which most often occurs during the placement of fresh concrete (Hurd 2005). This can result in the unstable, new concrete member collapsing. If the member happens to be an important structural member, it can lead to the collapse of the entire structure. This invariably results in the loss of life. During the construction of a multi story building in Fairfax County, VA, fourteen workers were killed and thirty four were injured in 1973 when a portion of the building progressively collapsed (Leyendecker and Fattal 1977). In another incident at Willow Island WV, 51 workers were killed, when a cooling tower that was being constructed collapsed (Lew 1982). The National Bureau of Standards diagnosed that the reason for this was the premature removal of formwork (Will Hansen 2006). The construction failure of the Condominium building in Cocoa Beach in Florida (Lew et al. 1982a, Lew et al. 1982b) is another major accident due to the same reason.

This thesis follows the style of the Journal of Construction Engineering and Management.

Thus the motivation for proper removal of formwork is twofold. First, it should be removed as early as possible so that it does not prevent other activities from starting. Second, it should not be removed so early that, concrete has not reached a minimum strength, which can result in the collapsing of the member and hence loss of life. Thus the aim is monitor the concrete and remove the formwork as soon as it can be determined that it has gained minimum strength. This ensures that the concrete member does not collapse as well as making sure that no time is lost.

As a rule of thumb forms for vertical members, like columns forms are removed in 3 days while for horizontal members like beams it varies from 7-14 days. Usually concrete cylinders are cast using the same mix of concrete as used on the site, transported to a lab and cured and tested there. The rationale being that the strength of the concrete cylinder will reflect the strength of concrete poured on the site. The short coming of this method is that while the standard cured concrete cylinders are tested after 28 days, the formworks are removed much before that, rendering the usage of this method unsuitable to determine the strength of freshly poured concrete. The concrete cylinder method also fails to make allowances for difference in environment and curing conditions, in gaining of strength. The reliability of this method is questionable, considering that the cocoa beach condominium project collapsed after using laboratory cylinders to determine actual strength of concrete slabs (Ghosh 2008). This means that the strength of fresh concrete has to be determined in situ. The strength of concrete has to be determined in a way which will not affect the structural integrity of the concrete member and at the same time is reliable. This suggests that a non destructive testing method should be used to measure the strength.

2. LITERATURE REVIEW

2.1 Concrete Maturity Method

The concrete maturity method is one such method which can be utilized to determine strength in -situ. This technique is based upon the measured temperature history of concrete during the curing period. The combined effects of time and temperature lead to a single parameter termed maturity (Ansari et al. 1999).

The maturity rule according to Saul (1951) is:
"Concrete of the same mix at the same maturity (reckoned in temperature-time) has approximately the same strength whatever combination of temperature and time goes to make up that maturity."

During curing chemical reactions take place between cement and water, which is exothermic. Thus it is possible to draw a relationship between the temperature change of concrete during early stages and its strength (McIntosh 1949, Saul 1951, McDaniel 1915, Wiley 1929).

Two maturity functions that have gained prominence are the Nurse-Saul maturity function and Arrhenius maturity function (Saul 1951, Freiesleben-Hansen 1977).The Nurse-Saul function is simpler to use as compared to the Arrhenius function.
The Nurse-Saul function is given as:

$$M = \varepsilon\ (T\text{-}T0\Delta)t$$

M=Maturity Index, °C-hours

T=Average concrete temperature

T0= Datum temperature

Δt= time interval (hours or days)

A calibration curve plotting time and concrete maturity for the given concrete composition can be carried out in a laboratory. After monitoring the temperature on site and calculating the concrete maturity index the actual onsite strength of concrete can be calculated using the curve plotted in the laboratory. A sample graph is shown in Fig. 2.1.

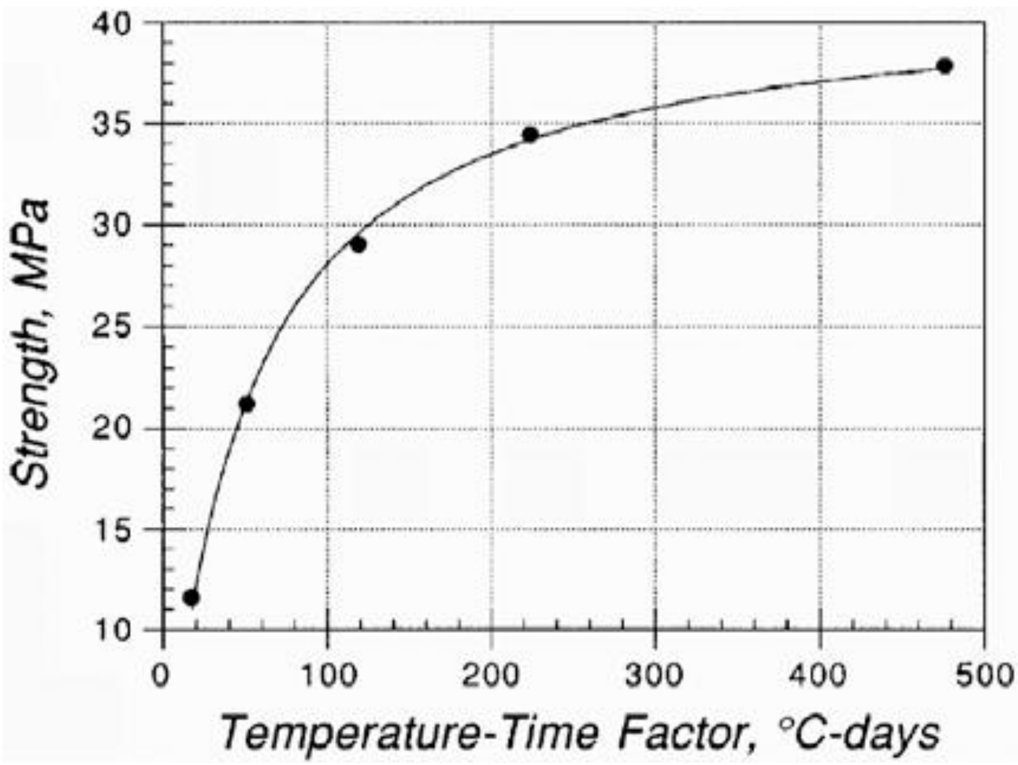

FIG. 2.1. Graph of Maturity Index vs Concrete Strength gain over time

Source: (Paul M. Goodrum 2004)

The temperature of concrete can be monitored continuously. This means that the maturity index and strength can be monitored continuously (Tepke et al. 2004). This is a huge leap forward and has a lot of potential applications. If the strength of fresh concrete can be monitored continuously it is possible to identify the point in time at which concrete finally achieves strength. This time would be the time when formwork can be removed safely.

Concrete maturity method has been successfully applied in practice. The Webbers Falls Bridge, which carries I 40 over the Arkansas River, collapsed on May 26, 2002 after being struck by a barge. The bridge was reconstructed and reopened to traffic on July, 29, just 47 days later. “The maturity method was used successfully to expedite the concrete construction process” (Bai and Burkett 2006).

One of the approaches to monitor the temperature in real time is to use a temperature sensor and temperature recording device. This led to the usage of Thermocouples and Data loggers to monitor the temperature of concrete. The thermocouples are embedded within fresh concrete and are connected to the recording system using wires. This would lead to a lot of wiring, which is not advisable in an equipment and human intensive area like a construction site. Due to this a lot of wires were broken which meant that our objective of monitoring the temperature was not fulfilled (Goodrum 2004). Loose connections and confusion could also complicate the problem.

Followings are the benefits of using RFID tags over wired sensors (Kathawala 2008):

- Recorded temperature accuracy is +/-1°F;
- Constantly monitoring the In-Situ temperature. Data is available real time without use of wires;
- Temperature monitoring can continue for years wirelessly;
- Data can be transferred, analyzed and archived wirelessly;
- Eliminate concerns of harsh construction environment;
- Tags that can stand extreme conditions and temperatures resisting against environmental influences such as fogs and snow.

2.2 Radio Frequency Identification

It is possible to monitor the temperature, but the problem of extensive wiring has to be solved. It is possible to remove the wires totally by using devices called RFID's (Radio Frequency Identification Tags) which transmit information wirelessly. The RFID uses radio waves to send out information. A RFID system generally consists of three components: an antenna or coil, a transceiver (with decoder) and a transponder (RF tag) electronically programmed with unique information. The communication between the tag and the transceiver is enabled with the help of antennas. The data is acquired by the transceiver. The antenna when packaged with the transceiver and decoder is called a reader. The reader can be configured either as a handheld or a fixed-mount device (Domdouzis et al. 2007). The Tag is attached to the object which needs to be monitored. A reader is used which interrogates the tag wirelessly for information. On receiving the command from the reader, the tag responds by sending out the information. This information is received by the reader which then uses software to convert the wave signals in to data which can be read and stored for retrieval.

Usually a RFID is used only to transmit product information (almost like a barcode, but more easily and efficiently). It is also possible to combine a temperature sensor with an RFID. The temperature information can then be transmitted wirelessly. The idea then, is to embed the RFID integrated sensor within fresh concrete, to enable real time monitoring of temperature. While sacrificial sensors embedded in concrete have been used to monitor temperature during curing (Goodrum & Dai, 2004) there is not yet an accurate procedure by which RFID sensors could be used to wirelessly monitor temperature.

RFID tags were seen as a replacement for the Bar-codes which had been popular till then. RFID had certain advantages over Bar codes such as it did not need a direct line of sight to be read, RFID tag could be reused, it was more durable than bar codes, greater read range and greater storage capacity (Shepard 2005).

One of the earliest applications of RFID was its application by the British to distinguish friendly airplanes from the enemy airplanes. A transponder was placed on the British airplanes which identified it as a friend on receiving a radar signal ("The History of RFIDTechnology" 2005).

RFID's were initially used to identify and track materials and for preventing theft of articles ("The History of RFID Technology" 2005). In the recent past RFID systems were introduced to automate the collection of tolls on highways. The first ever highway electronic tolling system was installed in Oklahoma in 1991. One of the obstacles which prevented the wide spread usage of RFID tag initially was the lack of a standard and its cost (Catlin 2001).

On the 30th September 1999, the Auto-ID center was founded with collaboration of Massachusetts institute of Technology (MIT), Uniform Code Council (UCC) and companies like Gillette and Procter & Gamble (Garfinkel and Rosenberg 2006). It was a non-profit organization with which was aimed at creating a global RFID identification standard. In 2003 Auto-ID center was shut down and its work was divided among two organizations: EPCglobal and Auto-ID Labs. EPCglobal had the aim of commercializing and standardizing the technology while Auto-ID labs supervised the research of the Auto-ID centre (Gandhi 2007).

2.3 RFID Tags

A RFID tag contains two important components: an integrated circuit and an antenna. The antenna is the component which determines the read range. The integrated circuit consists of the microprocessor, memory and an antenna. The RFID tags can be classified in to two types based on their mode of data storage: Read/write and read only tags. Read only tags have a unique ID written in to it which when combined with a database can be used in identifying objects. RFID tags can also be distinguished as active or passive tags.

Passive tags depend on the electromagnetic field generated by the RFID reader in order to get activated. Active tags have batteries connected to which increases the read range of the tags as the tags do not depend on the electromagnetic field of the reader in order to get activated. (Bassi 1996).

The passive tags are cheaper, lighter, and smaller than active tags. Active tag can be used for long range application. There are two types of active tags: transponder and beacons. The transponder is activated only when a reader is present in the vicinity. This helps to conserve battery power on the tag. These types of active tags are used at toll station in highways. Another type is beacon which transmits signal at regular intervals.

2.4 RFID Reader

The reader communicates with the RFID tag. Although it is called reader it can also be used to write data on the tags. The components of reader depend on type of tag which is being used. The reader for a passive tag will have antenna with the capability of generating electro-magnetic field which is essential for charging the tag. The antenna can be integrated inside the reader or can be an external device separate from the reader. The data received by reader is managed and stored to data storage device through middleware software. This middleware software is also responsible for filtration of data and controls of reader (Thornton and Kleinschmidt 2006).

2.5 Operating Frequency of RFID

The RFID transponder and reader operate in the ranges of frequencies below:

• 125–134 kHz: This range is associated with the low frequency range which allows the detection of RFID tags in a range of less than 0.5 m. The data transfer rate in this range less than 1 kbit per second (Ward and van Kranenburg, 2006)

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• 13.56 MHz: This frequency which falls in the High frequency range allows the detection of RFID tags for a distance of up to 1.5 m. The data transfer rate for this specific frequency is approximately 25 Kbits per second (Ward and van Kranenburg, 2006)

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• 433–956 MHz: The frequencies which belong to this range are called as ultra-high frequencies. The frequencies of this range allow the detection of RFID tags for a distance of up to 100. The data transfer rate is 100 Kbits per second. The generated electromagnetic waves cannot penetrate water or metals. The frequencies at this range are used for applications in logistics (Ward and van Kranenburg, 2006).

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• 2.45 GHz: Tags using this frequency can be read by a RFID reader from a distance of ten meters. This specific frequency is characterized as microwave frequency. The data transfer rate for this specific frequency is up to 100 Kbits per second. The electromagnetic waves generated in this case cannot penetrate water or metal (Ward and van Kranenburg, 2006)

Summarized below in Table 2-1 released by the Danish Technology Institute, is the data for different frequency ranges (dti 2006).

TABLE 2-1. RFID Frequency Chart (courtesy Danish Technology Institute)

Band	LF Low frequency	HF High frequency	UHF Ultra high frequency	Microwave
Frequency	30–300kHz	3–30MHz	300 MHz–3GHz	2–30 GHz
Typical RFID Frequencies	125–134 kHz	13.56 MHz	433 MHz or 865 – 956MHz 2.45 GHz	2.45 GHz
Approximate read range	less than 0.5 metre	Up to 1.5 metres	433 MHz = up to 100 metres 865-956 MHz = 0.5 to 5 metres	Up to 10m
Typical data transfer rate	less than 1 kilobit per second (kbit/s)	Approximately 25 kbit/s	433–956 = 30 kbit/s 2.45 =100 kbit/s	Up to 100 kbit/s
Characteristics	Short-range, low data transfer rate, penetrates water but not metal.	Higher ranges, reasonable data rate (similar to GSM phone), penetrates water but not metal.	Long ranges, high data transfer rate, concurrent read of <100 items, cannot penetrate water or metals	Long range, high data transfer rate, cannot penetrate water or metal
Typical use	Animal ID Car immobiliser	Smart Labels Contact-less travel cards Access & Security	Specialist animal tracking Logistics	Moving vehicle toll

2.6 Concrete Maturity and RFID

RFID tags integrated with temperature sensors can be embedded in fresh concrete to monitor the temperature of concrete and thus the strength development. Using RFID's gets around the problem of extensive wiring that was posed by using thermocouples to monitor the temperature. With wireless sensors it is possible to monitor the temperature and hence strength of concrete in real time, 24 hours. The temperature can be measured at various points in the structure simultaneously from the office trailer. This would greatly speed up the process of concrete construction while at the same time making the monitoring of concrete temperature an easy task. The Michigan Department of Transportation has demonstrated an application the RFID temperature sensors to a road construction (Greenwood 2003, Hansen and Surlaker 2006).

2.7 Previous Research at Texas A&M

A research project was carried out by Dr.Julian Kang and Jasdeep Gandhi at the Department of Construction Science at Texas A&M to test the readability of RFID tags in fresh concrete. RFID tags were buried in a concrete cube measuring 2 x 3 x 2 at depths of 4”, 8” and 12”. It was found that the tags were not able to transmit information as soon as concrete was poured. The tags did not respond for the first three hours after concrete was poured, when water ratio was high in concrete. But as time went by the read range of the tags gradually increased. This seems to indicate that as the water content in concrete decreased the tags were able to transmit information better.

“The tag started giving the signal 4.5 hrs after pouring the concrete which can be because of the higher water content at time of pouring. The water content in concrete decreased with time and signal range of tag increased with time. “(Gandhi 2007)

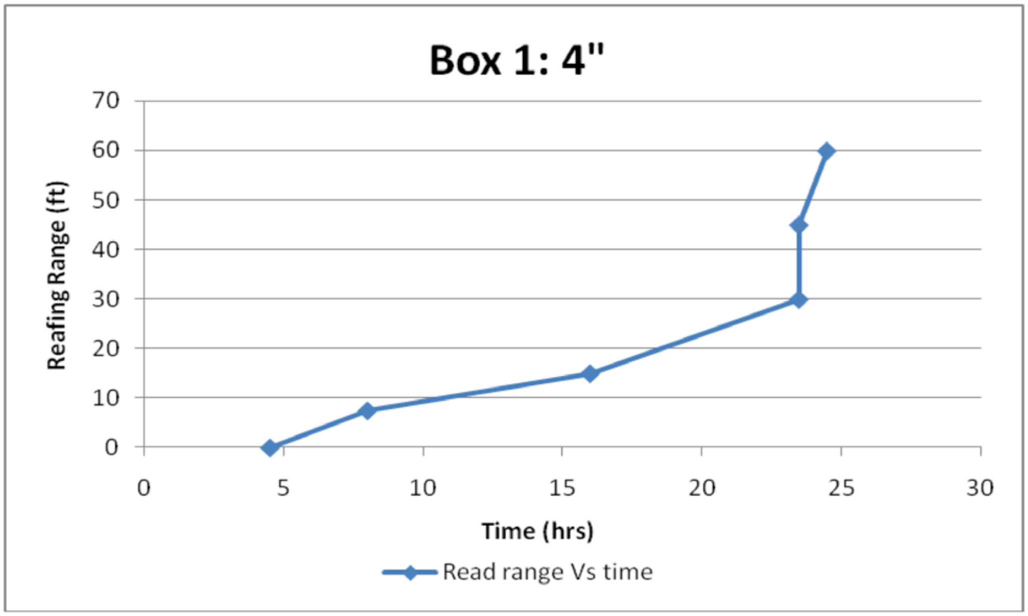

FIG. 2.2. Graph of tag in box 1 at depth 4”

Source: (Jasdeep Gandhi 2007)

From Fig. 2.2 it can be seen there was a sudden increase in the range 23 hrs after pouring the concrete.Thus we can surmise that water is the major impediment in the RFID tags being read in the early stage of curing of concrete. This would mean that we would have to have a wireless device capable of transmitting through water. This theory is supported by literature too. Water is one other material which has an effect on the range of the tag; the read range is reduced by the interference of water between the reader and the tag (Schneider 2003). The RFID readability decreases or stops if the tag is submerged in water (Fletcher 2005).The interference of water or liquid on the transmission of radio frequency between reader and tag has been tested and confirmed (Fletcher 2005).

2.8 Frequency of Tag and Ability to Penetrate Water

LF RFID systems have the strongest ability to read tags on objects with high water or metal content compared to any of the higher frequencies, the ability of HF to read tags on objects with high water or metal content is not as good as LF systems but stronger than UHF systems, one drawback to UHF systems is a limited ability to read tags on objects with or surrounded by high water or metal content (Ward and van Kranenburg 2006, Domdouzis et al. 2007).

3. PROBLEM STATEMENTS

3.1 Motivation

It has been established that water has a detrimental effect on the transmitting capability of water (Schneider 2003, Fletcher et al. 2005). It was found that in the experiment conducted by Gandhi UHF tags were used. From the literature it was found that lower the frequency, better the chances of the wave penetrating water. This would seem to lead to the fact that the lower the frequency of the RFID tag used, better would be its chances of being read from fresh concrete. This means that we could apply LF RFID as the tool to monitor temperature of fresh concrete, without having to worry about the effect of water on the RFID tag. From a literature survey it has been found that no experiment has been conducted to verify the fact that LF RFID can transmit better from within fresh concrete than other frequency RFID's, making it the ideal choice to monitor temperature in real time. This research aims to prove that fact that there is a relationship in the frequency of an RFID and its ability to penetrate fresh concrete and thus proving LF RFID can be used to circumvent the problem of water affecting transmission of RF signal.

3.2 Hypotheses

We hypothesize that the LF tag will be able to emit information from within concrete better than tags of other frequencies. This is based on our assumption that lower the frequency better its performance in water. In the study conducted by Gandhi it was seen that the UHF tag was not able to emit signals from within concrete for some time after it was poured. We think that using LF tag we will be able to detect the signal right from the beginning when concrete is poured.

3.3 Objective

The objective of the research is to find if there is a relationship between frequency of a tag and its ability to penetrate fresh concrete. The research will test LF, HF and UHF tags to determine which tag can be detected earliest from within a concrete block. The tag which can be detected the earliest would be an ideal candidate to be used in measuring concrete maturity. The tags are buried at different depths. The test will also try to determine the effect of depth of burial of tag with its readability. The variation in read range of the tag as concrete is cured is also monitored.

If it is proved that LF can penetrate fresh concrete better than RFID's of other frequencies, it would be a great leap forward to finding an efficient and easy way to determine in-situ concrete strength.

4. EXPERIMENTAL SETUP

4.1 Experiment Design

The objective of carrying out the experiment is to bring out the difference in penetration of signal in fresh concrete of RFID tags of different frequencies. Thus we will need to embed RFID's of different frequencies and observe their properties. Some of the parameters involved in the execution of the experiment are size of formwork, time, burying depth of RFID within concrete, distance of tag from reader, type of concrete, time, frequencies of tags and readers. The variables involved in this experiment are frequency of tag and time. Also, the read range of the tags might vary with frequency. For example the HF tag might have a maximum read range of 8” as compared to LF tag which has a maximum read range of 20”. If we were to place the LF and HF readers at 20” from the tags placed at the same level, only the LF tag will be detected as the HF tag has a maximum read range of 4” for the given tag and reader. So, in our experiment even if the HF tag can penetrate water better than the LF tag it will not be detected if the HF reader is placed beyond 4” from the tag. So, we will need to place the readers within the maximum read range of the respective tags. Temperature of the environment varies with time, which affects the curing of concrete. As the temperature of curing needs to be maintained during the experiment, the experiment was conducted in a closed environment in the wood shop at the Department of Architecture.

4.2 Synopsis of Experiment

- Formwork was created to hold concrete.
- RFID tags of three different frequencies were used, which were placed at a depth of 4”, 8” and 12”. A tag of each frequency was placed at each of these depths, thus making it a total of 9 tags in each formwork.
- Ready mix concrete was then poured into the forms.

- The readers were placed near the forms to check for RF signal.
- The time at which the signal of each tag was read was noted down.

4.3 Formwork

In an actual building we have beams and columns of differing sizes. Thus to generalize a result we would have to carry put the experiment with many specimens of differing sizes. However, as this is preliminary investigation we can use concrete blocks before scaling up the research to a bigger investigation. To determine the size of the concrete cube that needs to be cast we investigated the average size of a beam in the state of Texas. A survey conducted by Sterling Engineering and Design Company, tabulated the dimensions of the thickest member used in different commercial building projects (2007). The dimensions are given below in Table 4-1.

TABLE 4-1. Thickness of concrete members (courtesy Sterling engineering and design group)

Name of Project	City, State	Thickest concrete member
Velocity Gulch	Waco, Texas	2'10" X 1'8",
Serento group Condos	Houston, Texas	2'2"X2'
Alexan Fitzhugh	Dallas, Texas	2'4"X1'2"
Durock condos	Houston, Texas	1'4"X2'8"
Holly hill designs	San Antonio, Texas	1'8"X1'8"
Lake wyndmere	Woodlands, Texas	2'4"X1'2"
Alexan Silber	Houston, Texas	2'8"X1'
Baker and cypress apts	Dallas, texas	1'8"X1'8"
Alexan park lakes	Dallas, texas	2’X2’6”
Woodway square apts	Austin, Texas	2’3”X2’

From the above table it can be seen that the average dimension of a beam is 2ft x 2ft in the state of Texas. A height of 3 ft was chosen for the formwork in the test conducted by Gandhi based on the dimensions of the RFID tag. The same used in this case too. 3 such concrete cubes were cast. As this was a preliminary investigation this number was sufficient.

4.4 RFID Tags

RFID tags can be classified according to frequency as Low frequency, High frequency and Ultra high frequency. Low-frequency devices operate between 125 to 134 KHz and have a reading range of about 12 inches. High-frequency devices use the range of 3 to 30 MHz, and generally operate at 13.56 MHz UHF devices operate in a range of 400 to 950 MHz and have the highest reading range. The reading range increases with increase in frequency. However the ability to penetrate water decreases with increase in frequency. Furthermore, they can be divided as active and passive tags. Passive tags are dependent on the strength of the interrogating electromagnetic field. The use the power of this field to transmit information. As the passive tags are dependent on the reader their read range is limited. Active tags on the other hand have a built in battery and as such can be used over longer distances.

The frequency of the RFID tag is a variable in the experiment. As the aim was to find the variation in penetration power of different frequencies, we used a Low Frequency (LF) tag, High Frequency (HF) tag and Ultra High Frequency (UHF). These three classes of RFID tags apart from providing a good difference in their frequencies are available commercially too. For our case a 134.2 kHz, 13.56 MHz and 915 MHz tag were used. The LF and HF tag were passive tags whereas the UHF tag was active. While the LF and HF tags were from TI the UHF tag was from Identec solutions.

The RI-TRP-R9TD-30 120 mm cylindrical tags from Texas Instruments were used for the LF range. This tag operated at the 134.2 KHz range. The RI-TH1-CB1A-00 card transponder from Texas Instruments was used for the HF range. This operated at the 13.56 MHz range. The UHF i-q8 tag from Identec solutions was used. This which was active had an operating frequency of 915 MHz.

4.5 Tag Location

We placed tags at 4”, 8” and 12” from the surface of the formwork. At each depth we placed a LF, HF and UHF tag. The tags were placed parallel to the longest dimension, in this case 3ft. The aim of the experiment was not to determine the difference in readability due to depth. Tags were placed at different depths to enable the RFID tags to be read by the reader at least at one depth. The distance from the longest face was equal to the depth. The distance between two tags at the same depth was arbitrarily decided as 6”. The tags were held in position by wooden dowels and nylon string. The use of metal was avoided to avoid any variation that might occur due to that.

A small experiment was conducted to ensure that tags of differing frequencies did not interfere with each other. It was noticed that while more than one HF/UHF tag could be read at the same time, this was not possible in the case of LF tag. When two LF tags were close together neither of the tags were identified. Thus to minimize interference of the LF tags, we created a specific order of arranging the RFID tags. At the 4” level from left to right tags were placed as LF tag, UHF tag and HF tag. At the 8” level from left to right the tags were placed as HF tag, UHF tag and LF tag. . At the 12” level from left to right tags were placed as LF tag, UHF tag and HF tag. This ensures that there was sufficient distance between any two LF tags. The location of tags are shown in Fig. 4.1.

FIG. 4.1. Location of tags

4.6 RFID Reader

The reader that was used in this experiment could be used with a laptop. Some readers have built in antennas. In this experiment external antennas were designed and used for the LF and HF reader to extend its read range.

For the LF section, the RI-STU-MRD1 microreader was used. This reader could be plugged into a RD232 port and after being configured by the software provided, could be used to detect RFIDs. For the HF section, the TRF7960 reader was used. This reader could be plugged into a USB port and could be used. GUI software to install and run the device was downloaded from the TI website and used. For the UHF section, the identec i-card 3 reader was used. This could be plugged into a flash port and read. Necessary software was installed and used.

4.7 Concrete

The concrete used in the experiment had the same mix as the one used in the industry. Ready mix concrete was used to ensure consistency among the three concrete boxes. The concrete mix was design to achieve 3000 psi at 28 Days. The water cement ratio w/c was kept at 0.595 with the slump of 4 ½ inches. The mix was bought from Aggie land ready mix concrete company.

4.8 Assumptions and Limitations

1. This test is concerned only with the effect of water on RFID's. It does not take into consideration other variables like reinforcement.

2. Only 3 concrete samples were tested. Thus this constitutes only a preliminary study and not a generalization.

3. Time at which the RF signals were detected was the only measured parameter. This was used to determine the penetrative power of each frequency.

4. As this experiment was conducted in a wood shop there was a lot of machinery and wood and metal parts lying around

5. A lot of human traffic was involved in the woodshop during the day

6. No temperature was measured in this experiment.

7. The experiment was conducted in a closed environment and may not reflect actual site conditions.

5. IMPLEMENTATION OF EXPERIMENT

5.1 Trial Test

A pilot test was conducted to check if our assumption that LF tags could be better detected in water was true. A basin was filled with water. The depth of the basin was 2 feet. The LF tag was tied to the end of a 2 x 4 and immersed into the basin and the tag was monitored as shown in Fig. 5.1. It was noticed that the tag could be detected to a depth of 19 inches.

FIG. 5.1. Trial test of low frequency tag in water

A similar experiment was repeated with the HF tag as shown in Fig. 5.2. The read range of the tag was around 4” and that this was a dramatic decrease from the read range in free air which was 7.9”.

FIG. 5.2. Trial test of high frequency tag in water

The UHF was immersed in a tub of water as shown in Fig. 5.3 and it was observed that the tags could be detected in water, but only till a depth of approximately 1 feet.

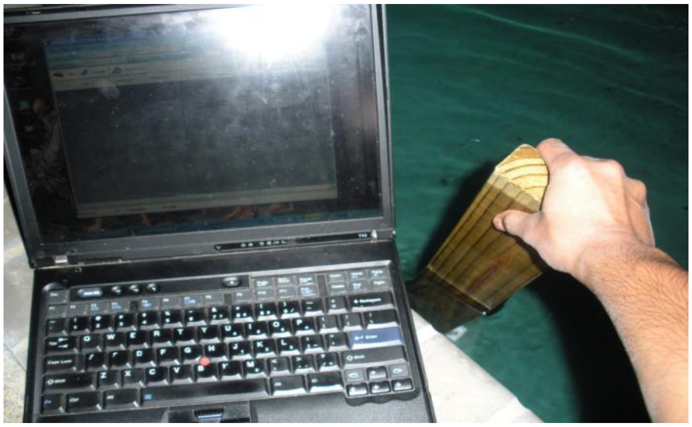

FIG. 5.3.   Trial test of ultra high frequency tag in water

5.2 Implementation

Wooden formworks to hold the concrete were made using wooden panels and lumber. The tags were arranged as shown in Fig. 5.4.The three formworks were lined up in the Wood shop of the college of Architecture in Langford building C as shown in Fig. 5.5. The concrete truck was backed up to the loading dock and concrete was carefully poured into the forms, to avoid displacing the RFID tags. After this the readers were continuously monitored for signs of signal from the RFID tags embedded. The time at which the signals were detected was noted down.

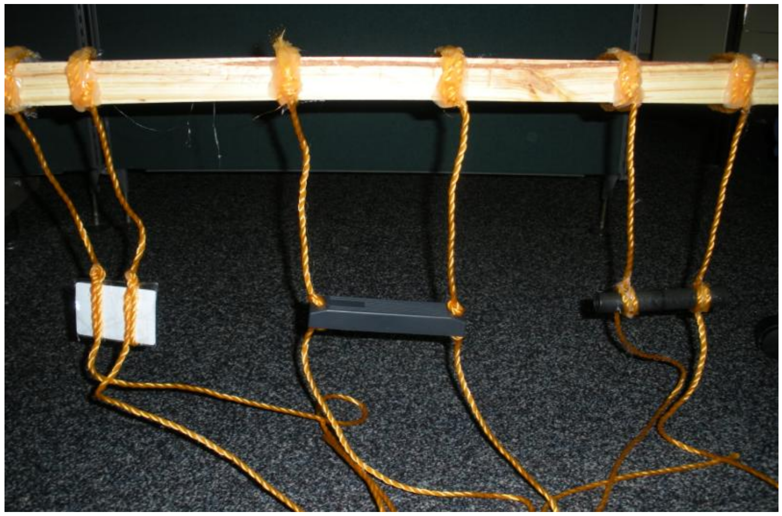

FIG. 5.4. Arrangement of tags

FIG. 5.5. Formwork and pouring of tags

5.3 Test Results

The concrete truck was brought in to the loading bay of the wood shop and the concrete was poured in to all the formworks by 3.30pm. The concrete was immediately checked for RFID signals. The following table gives the time elapsed since concrete was poured when the signals of the various tags could be detected.

TABLE 5-1. Time of detection of tags in Box 1

Box1								
Low Frequency tag			Ultra High Frequency tag			High Frequency tag		
at 4"	at 8"	at 12"	at 4"	at 8"	at 12"	at 4"	at 8"	at 12"
0	0	0	15 min	15 min	1 hr 36 mins	3 hrs 17 mins	not read	not read

TABLE 5-2. Time of detection of tags in Box 2

Box2								
Low Frequency tag			Ultra High Frequency tag			High Frequency tag		
at 4"	at 8"	at 12"	at 4"	at 8"	at 12"	at 4"	at 8"	at 12"
0	0	0	15 min	40 min	3 hrs 1 min	4 hrs 25 mins	not read	not read

TABLE 5-3. Time of detection of tags in Box 3

Box3								
Low Frequency tag			Ultra High Frequency tag			High Frequency tag		
at 4"	at 8"	at 12"	at 4"	at 8"	at 12"	at 4"	at 8"	at 12"
0	0	0	15 min	40 min	1 hr 36 mins	not read	not read	not read

It can be seen from Table 5-1,Table 5-2 and Table 5-3 that all the tags were detected except for the HF tags at the 8”and 12” levels and one HF tag at the 4” level.

The Low frequency tags were detected immediately after the concrete was poured at all depths (4”, 8”, 12). They were detected immediately till a distance of 20”from the tag, which also happens to be the maximum read range of the LF tag in free air.

The HF tags were not detected immediately and took on an average, around 4 hours to be detected at the 4” level. Only two of the tags at the 4” level could be detected. None of the other tags could be detected till the end of the experiment.

The UHF tags placed at the 4” level could be detected 15 minutes after concrete was poured. For this purpose the reader had to be kept really close to the formwork around 15” from the formwork. The tags at the 8” level could be detected after 30 minutes when the readers were placed close to the formwork. The tags at the 12” level took on an average 2 hours to be detected from the vicinity of the formwork.

5.4 Data Analysis

The LF tags worked exactly as per the hypothesis that a lower frequency tag would be able to better penetrate water. It was possible to read the tags at all the depths instantaneously. However the read range of the tag was restricted to 20". This is the only drawback of the LF tag. A higher read range would be necessary for it to be used on an actual construction site. Some of the factors that can be used to increase the read range of the LF tag are:

1. Reader Output Power

2. Reader Antenna Size

3. Tag antenna size

4. Environmental effects

5. Tag orientation

The reason the performance of the HF card degraded in concrete is because it uses an aluminum foil antenna which is more susceptible to the environment changing the relative permeability. A copper wire antenna could have fared better in this condition, increasing the chances of detecting the tag. Moreover a passive tag was used. The read range and chances of detection could have been increased had an active tag been used. The power of the reader that was used was also very less which might have contributed to the tag not being detected.

The UHF tags are affected by the depth at which they are buried, which conforms the finding made by Gandhi. The time to detect the tag increased with increase in depth. The increase in read range was monitored over 5 days. For detecting the tags at the 12" level, the reader had to placed at a distance of less than 15" from the form. The reception of the tags was bad and the reader could not immediately detect the tag when placed near the formwork. The reader took some time to process and detect the tag.

The LF tags could be read at all the depths. This would seem to indicate that the LF tags that were used in this experiment were not affected by the depth at which the tag was buried. All the LF tags in the experiment were also detected immediately after concrete was poured, which might indicate that the tags used in the experiment were not affected by water present in concrete. On the other hand, the UHF tags that were used in the experiment showed a variation in readability with depth and could not be detected immediately after the concrete was poured. It can be seen that on comparing the LF tags and UHF tags, the LF tags undoubtedly have a far greater power to penetrate concrete than UHF tags based on the time taken for their detection and their readability with increase in depth of burial of tag. The results of the test would seem to indicate that LF is a better choice of RFID tag as compared to the UHF for harsh environmental conditions. Considering that a real construction site is bound to have greater disturbances than in the test that was conducted, LF tags might be a better pick.

The maximum read range of the LF tag was approximately 20” which was reached immediately after concrete was poured. The HF tags at the 4” level could be read at a maximum distance of 4”. The read range of the UHF tags increased with increase in time. The variations in read range of the UHF tags is discussed in the section below

5.5 Read Range of UHF Tags

The experiment was set up as shown below:

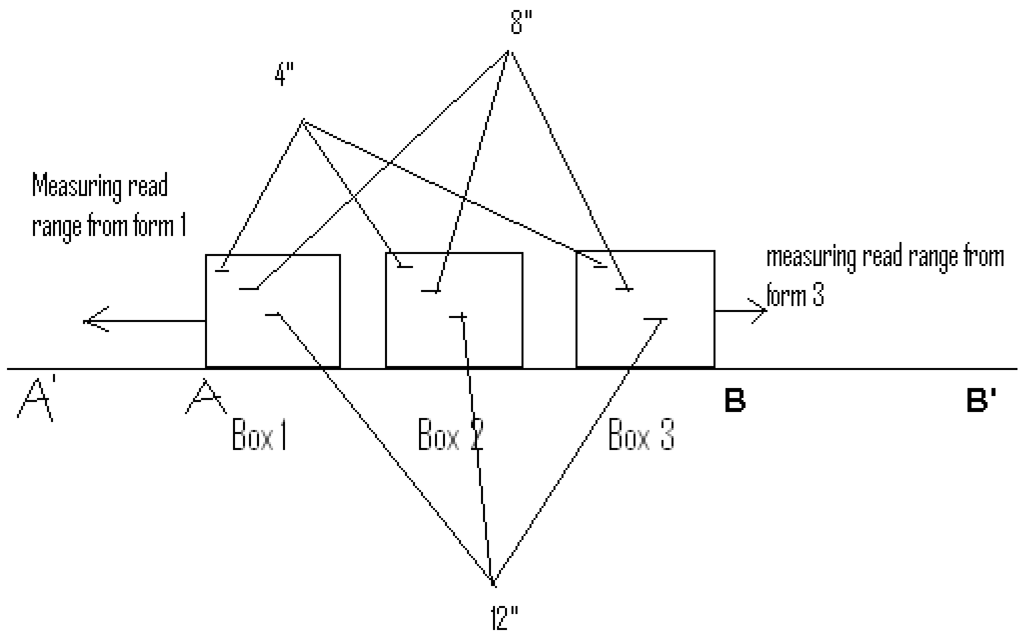

FIG. 5.6. Points from which the read range measurements are made

Point A lies on the edge of Box1as shown in the Fig. 5.6. Point B lies on the edge of the Box 3 as shown in the Figure 5.6. The observer was moving away from point A as shown by the arrow in the Figure 5.6, while checking for the presence of RFID tags. When a tag was detected, that point is marked as A'. AA' is the read range for the tag that was detected at the point A'. A similar exercise is done from point B for detection of tags. The read range of tags is BB'. For the sake of convenience the read range of tags measured from point A are termed as read ranges from form 1 and those from point B as read ranges from form 3.

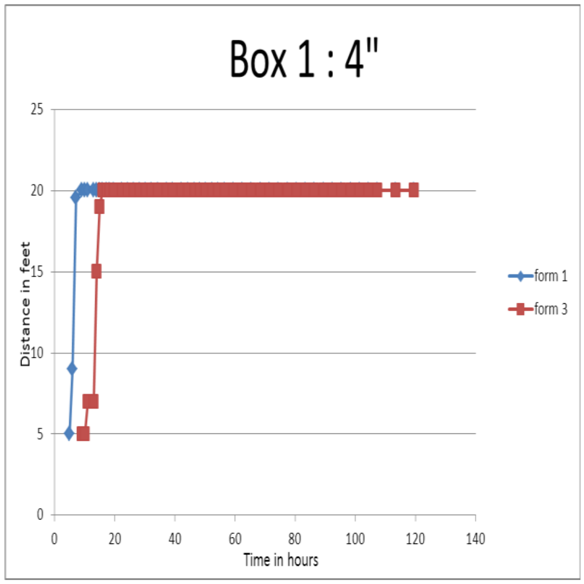

FIG. 5.7. Graph of tag in box 1 at a depth of 4”

Fig. 5.7 shows the variation of read range with time of tag in box 1 at a depth of 4” with time. The read ranges are measured from two points, Point A and point B as shown in Fig. 5.6. The read ranges measured from point A having a length of AA’(in feet) are symbolised as form 1 in Fig. 5.7. The read ranges measured from point B and having a length of BB’(in feet) are symbolised as form 3 in Fig. 5.7. The tag was first detected at a distance of 5 ft from form 1 at 5 hrs. The tag was first detected from form 3 at a distance of 5ft after 9 hours.The distance of detection of tag from form 1 was slightly greater than that of distance of detection from form 3 till 15 hrs after which they remained the same from both the forms. The reason for the tag being detected earlier from the side of form 1 could be because there is no obstacle between the tag and the reader. However when the tag is detected from the side of form 3, Boxes 2 and 3 act as obstacles to the tag.The cocnrete present in these boxes could be responsible for interfering with the RF waves.

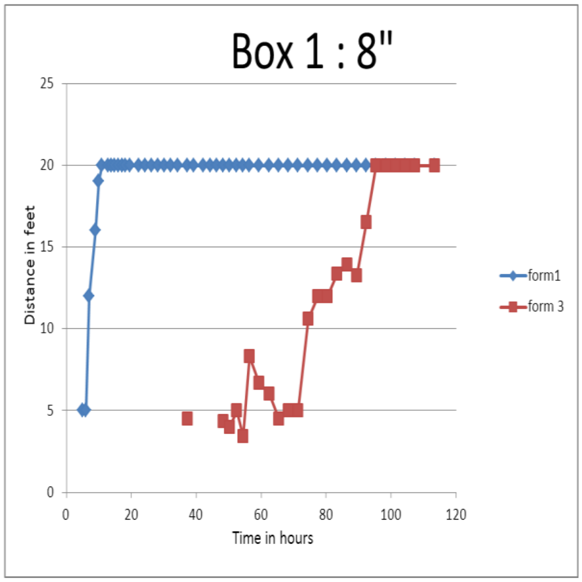

FIG. 5.8. Graph of tag in box 1 at a depth of 8”

Fig. 5.8 shows the variation of read range with time of tag in box 1 at a depth of 8” with time. The read ranges are measured from two points, Point A and point B as shown in Fig. 5.6. The read ranges measured from point A having a length of AA’(in feet) are symbolised as form 1 in Fig. 5.8. The read ranges measured from point B and having a length of BB’(in feet) are symbolised as form 3 in Fig. 5.8.The tag was first detected from form 1(point A) at a distance of 5 ft after 5 hrs. On the other hand, this tag could be detected from form3(point B) at a distance of 4.5 ft only after 37.5 hours. The read range on measured from form 3 took a longer time to catch up with the read range from form 1. The detection of tag from the side of form 3 took a longer time than detection from form 1. When the read range was measured from form 1(point A) there was no obstacle between the tag and the reader. On the other hand, when the read range was measured from form 3(point B) box 2 and box 3 act as obstacles for this tag. It is possible that the tag gets detected later on the side of form 3 becausen the concrete boxes are acting as obstacles.

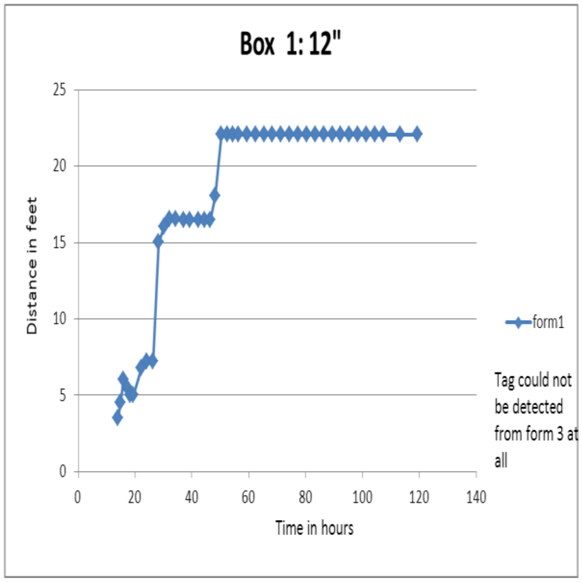

FIG. 5.9. Graph of tag in box 1 at a depth of 12”

Fig. 5.9 shows the variation of read range with time of tag in box 1 at a depth of 12” with time. The read ranges are measured from two points. Point A and point B as shown in Fig. 5.6. The read ranges measured from point A having a length of AA’(in feet) are symbolised as form 1 in Fig. 5.9. The read ranges measured from point B and having a length of BB’(in feet) are symbolised as form 3 in Fig. 5.9. This tag which is buried at a depth of 12” could be detected on the side of form 1(point A) only. It could not be detected at all when the reader was placed on the side of form 3(point B). There is something hindering the detection of the tag when the reader is placed on the side of form 3(along BB’). It could be the presence of concrete box 2 and box 3 which are affecting the detection of this tag along BB’.

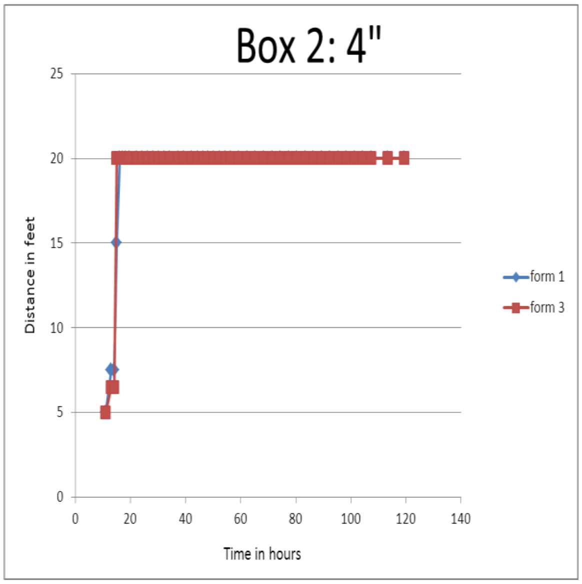

FIG. 5.10. Graph of tag in box 2 at a depth of 4”

Fig. 5.10 shows the variation of read range with time of tag at a depth of 4” in box 2.

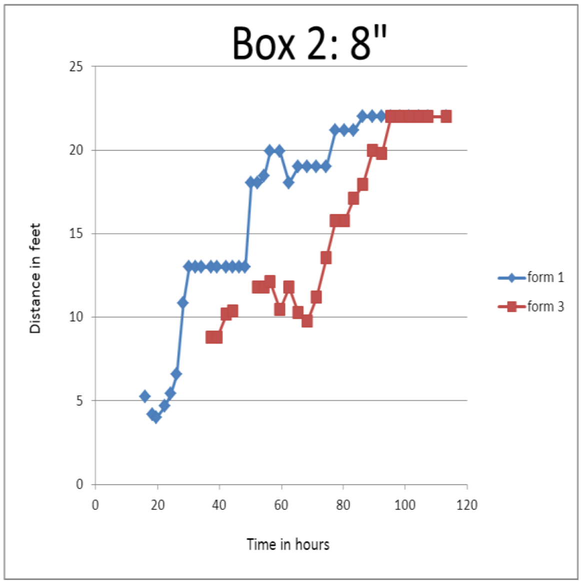

FIG. 5.11. Graph of tag in box 2 at a depth of 8”

Fig. 5.11 shows the variation of read range with time of tag at a depth of 8” in box 2.

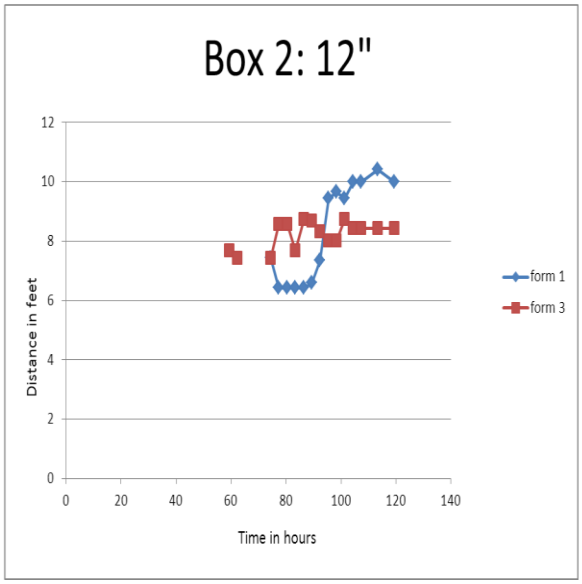

FIG. 5.12. Graph of tag in box 2 at a depth of 12”

Fig. 5.12 shows the variation of read range with time of tag at a depth of 12” in box 2.

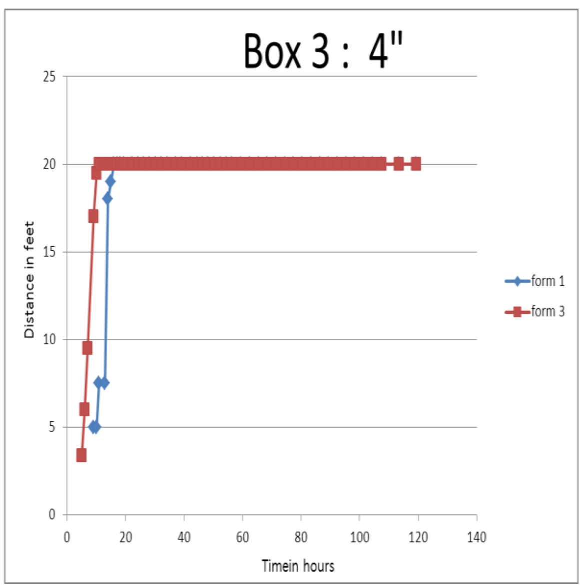

FIG. 5.13. Graph of tag in box 3 at a depth of 4”

Fig. 5.13 shows the variation of read range with time of tag at a depth of 4” in box 3.

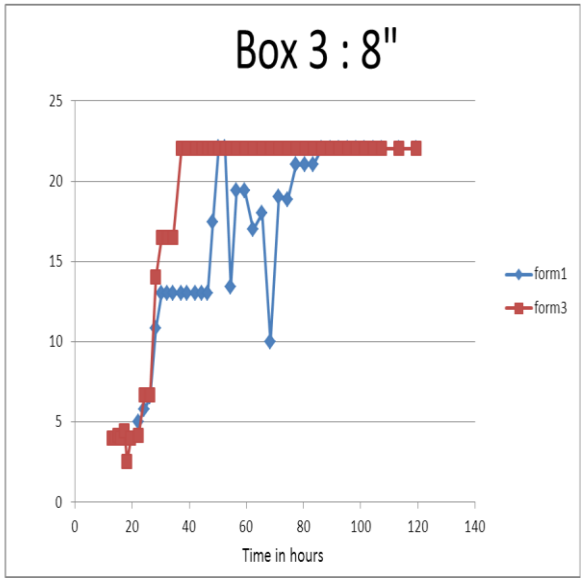

FIG. 5.14. Graph of tag in box 3 at a depth of 8”

Fig. 5.14 shows the variation of read range with time of tag at a depth of 8” in box 3.

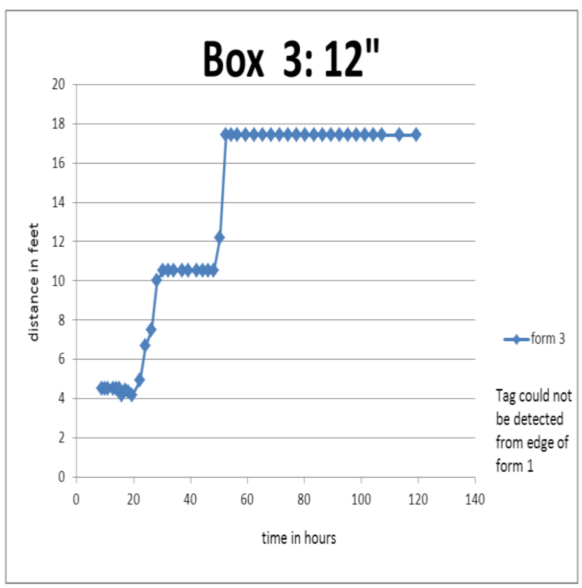

FIG. 5.15. Graph of tag in box 3 at a depth of 12”

Fig. 5.15 shows the variation of read range with time of tag at a depth of 12” in box 3.

The Figures above show the variation of read range of tags buried at different depths along two directions (AA" and BB'). The trend that can be seen from the Figures is that the tags could be detected the earliest from the side which did not have any interference. When, a concrete block was present between the tag and the reader, the tags took a longer time to be detected than when there was no concrete block between the tag and the reader. This might seem to be an indication that the when obstacles such as concrete blocks are placed between a tag and a reader, the read range is reduced.

6. CONCLUSION

6.1 Summary

The hypotheses tested in this research was that the frequency of RFID tags has something to do with the readability of tags embedded in fresh concrete. The test implemented in a controlled room showed that low frequency tags have a better capability to penetrate water than any other frequency RF tags used in the experiment. The low frequency RFID tags were detected at all depths as soon as the concrete was poured. The High Frequency tags could be detected only at the 4” level. This could probably be because an Aluminum foil antenna, which is easily affected by the environment conditions, was used. Moreover, a passive HF tag was used which has a limited read range. The power of the HF reader was less which could also have contributed to limited detection of HF tag. The UHF tags buried at the 4” level were detected 15 minutes after the concrete was poured. The UHF tags buried at 8” were detected half an hour after the concrete was poured. The UHF tags buried at 12” were detected 2 hours after concrete was poured.

The depth of burial of tag did not have any effect on the readability of the LF tag. Fresh concrete also did not have any impact on the readability of the LF tag. Depth of burial of tag and fresh concrete had an impact on the performance of the UHF tag. Comparing readability of LF and UHF tags embedded at 4 inches, 8 inches and 12 inches in fresh concrete would seem to indicate that LF tags perform better than HF tags.

The read ranges of the UHF tag was measured in two ways. In the first case there was only air between the tag and the reader. In the second case, concrete blocks were present between the tag and the reader. It was found that tags could be more easily detected in free air than when concrete blocks were placed between the tag and the reader. Concrete blocks placed nearby might be having an impact on the propagation of the Radio wave, which is causing the tag to be detected later when a concrete block was present between the tag and reader.

6.2 Impact of Research

RFID tags that have been used previously in determining concrete maturity index did not work well due to the interference of water in concrete. This research tries to address the issue of interference of water by using Low Frequency tags. Low frequency tags seem to be able to transmit information from within fresh concrete very well. This research provides a promising solution to monitor the strength of concrete structural members in real time. Monitoring strength of concrete structural members in real time will help expedite the project and save money.

6.3 Future Research

The experiment was carried out using tags and readers from a particular vendor. The number of test cases was limited to three. As such the findings that are mentioned above cannot be generalized for entire industry and all other RFID tags. Further research is needed to generalize these conclusions.

It was found that LF tags used in the experiment did a good job of transmitting information from within fresh concrete. Further research is necessary to determine its reliability. A pilot study will need to done to ensure that it can be used in onsite conditions too. The read range of LF is another issue. The read rang is not as high as we would like to be, to be used on a construction site. The read range of the LF tag can be increased by using active tags and increasing the power of the antenna. Factors which influence read range of LF tag need to be studied, so that read range of LF tags can be increased. LF tags integrated with sensors are not commercially available on the market yet. Such a device may need to be fabricated and its reliability in predicting the concrete strength needs to be proven.

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APPENDIX A

Read range chart of UHF tag

Box 1: 4"		
Cumulative time(Hrs)	Distance from 1 (ft)	Distance from 3 (ft)
5	5	
6	9	
7	19.5	
9	20	5
10	20	5
11	20	7
13	20	7
14	20	15
15	20	19
16	20	20
17.30	20	20
18.30	20	20
19.55	20	20
22.30	20	20
24.30	20	20
26.30	20	20
28.30	20	20
30.30	20	20
32.30	20	20
34.30	20	20
37.30	20	20
39.30	20	20
42.30	20	20
44.45	20	20
46.45	20	20
48.30	20	20
50.30	20	20
52.45	20	20
54.45	20	20
56.45	20	20
59.45	20	20
62.45	20	20
65.45	20	20

68.45	20	20
71.45	20	20
74.45	20	20
77.45	20	20
80.45	20	20
83.45	20	20
86.45	20	20
89.45	20	20
92.45	20	20
95.45	20	20
98.45	20	20
101.45	20	20
104.45	20	20
107.45	20	20
113.45	20	20
119.45	20	20

Box 1 : 8"		
Cumulative time	Distance from form 1(ft)	Distance from form 2 (ft)
5	5	
6	5	
7	12	
9	16	
10	19	
11	20	
13	20	
14	20	
15	20	
16	20	
17.30	20	
18.30	20	
19.55	20	
22.30	20	
24.30	20	
26.30	20	
28.30	20	

30.30	20	
32.30	20	
34.30	20	
37.30	20	4.5
39.30	20	
42.30	20	
44.45	20	
46.45	20	
48.30	20	4.33
50.30	20	4
52.45	20	5
54.45	20	3.42
56.45	20	8.33
59.45	20	6.67
62.45	20	6
65.45	20	4.5
68.45	20	5
71.45	20	5
74.45	20	10.58
77.45	20	12
80.45	20	12
83.45	20	13.33
86.45	20	13.92
89.45	20	13.25
92.45	20	16.5
95.45	20	20
98.45	20	20
101.45	20	20
104.45	20	20
107.45	20	20
113.45	20	20
119.45	20	20

Box 1 : 12"		
Cumulative time	Distance from form 1(ft)	Distance from form 3(ft)
5		
6		
7		

9		
10		
11		
13		
14	3.5	
15	4.5	
16	6	
17.30	5.5	
18.30	5	
19.55	5	
22.30	6.75	
24.30	7.17	
26.30	7.17	
28.30	15	
30.30	16	
32.30	16.5	
34.30	16.5	
37.30	16.42	
39.30	16.42	
42.30	16.42	
44.45	16.42	
46.45	16.42	
48.30	18	
50.30	22.08	
52.45	22.08	
54.45	22.08	
56.45	22.08	
59.45	22.08	
62.45	22.08	
65.45	22.08	
68.45	22.08	
71.45	22.08	
74.45	22.08	
77.45	22.08	
80.45	22.08	
83.45	22.08	
86.45	22.08	
89.45	22.08	
92.45	22.08	

95.45	22.08	
98.45	22.08	
101.45	22.08	
104.45	22.08	
107.45	22.08	
113.45	22.08	
119.45	22.08	

Box 2 : 4"		
Cumulative time(hrs)	Distance from form 1(ft)	Distance from form 3(ft)
5		
6		
7		
9		
10		
11	5	5
13	7.5	6.5
14	7.5	6.5
15	15	20
16	20	20
17.30	20	20
18.30	20	20
19.55	20	20
22.30	20	20
24.30	20	20
26.30	20	20
28.30	20	20
30.30	20	20
32.30	20	20
34.30	20	20
37.30	20	20
39.30	20	20
42.30	20	20
44.45	20	20
46.45	20	20
48.30	20	20
50.30	20	20
52.45	20	20

54.45	20	20
56.45	20	20
59.45	20	20
62.45	20	20
65.45	20	20
68.45	20	20
71.45	20	20
74.45	20	20
77.45	20	20
80.45	20	20
83.45	20	20
86.45	20	20
89.45	20	20
92.45	20	20
95.45	20	20
98.45	20	20
101.45	20	20
104.45	20	20
107.45	20	20
113.45	20	20
119.45	20	20

Box 2 : 8"		
Cumulative time(hrs)	Distance from form 1(ft)	Distance from form 3(ft)
16	5.25	
17.3		
18.3	4.17	
19.55	4	
22.3	4.67	
24.3	5.42	
26.3	6.58	
28.3	10.83	
30.3	13	
32.3	13	
34.3	13	
37.3	13	8.77
39.3	13	8.77
42.3	13	10.19

44.45	13	10.35
46.45	13	
48.3	13	
50.3	18	
52.45	18	11.77
54.45	18.42	11.77
56.45	19.92	12.10
59.45	19.92	10.44
62.45	18	11.77
65.45	19	10.27
68.45	19	9.77
71.45	19	11.19
74.45	19	13.52
77.45	21.17	15.77
80.45	21.17	15.77
83.45	21.17	17.10
86.45	22	17.94
89.45	22	19.94
92.45	22	19.77
95.45	22	22.00
98.45	22	22.00
101.45	22	22.00
104.45	22	22.00
107.45	22	22.00
113.45	22	22.00
119.45	22	22.00

Box 2: 12"		
Cumulative time(Hrs)	Distance from form 1(ft)	Distance from form 3(ft)
5		
6		
7		
9		
10		
11		
13		
14		
15		
16		

17.30		
18.30		
19.55		
22.30		
24.30		
26.30		
28.30		
30.30		
32.30		
34.30		
37.30		
39.30		
42.30		
44.45		
46.45		
48.30		
50.30		
52.45		
54.45		
56.45		
59.45		7.67
62.45		7.42
65.45		
68.45		
71.45		
74.45	7.42	7.42
77.45	6.42	8.58
80.45	6.42	8.58
83.45	6.42	7.67
86.45	6.42	8.75
89.45	6.58	8.67
92.45	7.33	8.33
95.45	9.42	8
98.45	9.67	8
101.45	9.42	8.75
104.45	10	8.42
107.45	10	8.42
113.45	10.42	8.42
119.45	10	8.42

Box 3 : 4"		
Cumulative time(hrs)	Distance from form 1(ft)	Distance from form 3(ft)
5		3.42
6		6
7		9.5
9	5	17
10	5	19.5
11	7.5	20
13	7.5	20
14	18	20
15	19	20
16	20	20
17.30	20	20
18.30	20	20
19.55	20	20
22.30	20	20
24.30	20	20
26.30	20	20
28.30	20	20
30.30	20	20
32.30	20	20
34.30	20	20
37.30	20	20
39.30	20	20
42.30	20	20
44.45	20	20
46.45	20	20
48.30	20	20
50.30	20	20
52.45	20	20
54.45	20	20
56.45	20	20
59.45	20	20
62.45	20	20
65.45	20	20
68.45	20	20
71.45	20	20
74.45	20	20

77.45	20	20
80.45	20	20
83.45	20	20
86.45	20	20
89.45	20	20
92.45	20	20
95.45	20	20
98.45	20	20
101.45	20	20
104.45	20	20
107.45	20	20
113.45	20	20
119.45	20	20

Box 3 : 8"		
Cumulative time(hrs)	Distance from form 1 (ft)	Distance from form 3(ft)
5		
6		
7		
9		
10		
11		
13		4
14		4
15		4.17
16		4
17.30		4.42
18.30		2.5
19.55		4
22.30	5	4.17
24.30	5.75	6.67
26.30	6.58	6.67
28.30	10.83	14
30.30	13	16.5
32.30	13	16.5
34.30	13	16.5
37.30	13	22

39.30	13	22
42.30	13	22
44.45	13	22
46.45	13	22
48.30	17.42	22
50.30	22.08	22
52.45	22.08	22
54.45	13.42	22
56.45	19.42	22
59.45	19.42	22
62.45	17	22
65.45	18	22
68.45	10	22
71.45	19	22
74.45	18.83	22
77.45	21	22
80.45	21	22
83.45	21	22
86.45	22	22
89.45	22	22
92.45	22	22
95.45	22	22
98.45	22	22
101.45	22	22
104.45	22	22
107.45	22	22
113.45	22	22
119.45	22	22

Box 3 : 12"	
Cumulative time(hrs)	Distance from form 3(ft)
5	
6	
7	
9	4.5
10	4.5
11	4.5
13	4.5
14	4.5

15	4.5
16	4.17
17.30	4.42
18.30	4.33
19.55	4.17
22.30	4.92
24.30	6.66
26.30	7.5
28.30	10
30.30	10.5
32.30	10.5
34.30	10.5
37.30	10.5
39.30	10.5
42.30	10.5
44.45	10.5
46.45	10.5
48.30	10.5
50.30	12.17
52.45	17.42
54.45	17.42
56.45	17.42
59.45	17.42
62.45	17.42
65.45	17.42
68.45	17.42
71.45	17.42
74.45	17.42
77.45	17.42
80.45	17.42
83.45	17.42
86.45	17.42
89.45	17.42
92.45	17.42
95.45	17.42
98.45	17.42
101.45	17.42
104.45	17.42
107.45	17.42

113.45	17.42
119.45	17.42

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